Contagion across US and EU financial markets: Evidence from the CDS markets

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Abstract

This study investigates whether contagion occurred during the recent global financial crisis across EU and US financial markets. The methodology used to test for contagion is the Forbes and Rigobon cross-correlation test, the Li and Zhu non-parametric test, the Fry et al. coskewness test and the Hsiao cokurtosis and covolatility tests. These tests are applied to a set of bank sector CDS, insurance sector CDS, sovereign bonds, equity and volatility indices. The findings indicate significant evidence of contagion, especially through the channels of higher order moments.

Keywords: Cokurtosis; Correlation; Coskewness; Covolatility; Financial contagion; Financial crisis

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1. Introduction

The 2007-2008 financial crisis, originated in the US subprime mortgage market and spread with devastating effects to the rest of the sectors of the US economy, as well as the global financial markets, is considered to be the most serious recession since World War II. The problem in the mortgage market, which was a relatively small part of the US economy, spread to other financial sectors through the Collateralized Mortgage Obligations (CMOs), which are a type of collateralized debt obligations (CDOs). The problems in the mortgage market became more pronounced by the presence of credit default swaps (CDS), which were used as an insurance contract for the various CMOs. The plunge of the prices in the mortgage markets caused the CMOs to drop in value and since the demand of CMOs was very low they were no longer being traded, making it difficult to price them. This triggered the protection payments of the CDSs and caused financial institutions to suffer great losses. The default of Lehman caused substantial turmoil to the global financial markets, leading to the failure of a number of financial institutions and investors selling high risk assets, such as stocks and derivative securities, causing a sharp drop in asset prices.

There are numerous studies that examine how a crisis transmits through the CDS channel, as well as the degree of comovements between CDSs and other asset classes. Some recent research on the relationship between sovereign bonds and CDS includes those of Pan and Singleton (2008), Longstaff et al. (2011), and Ang and Longstaff (2013). A strand of literature that focuses on bank sector CDS includes those by Acharya et al. (2014) who focus on financial sector bailouts and document, using CDS data, that both bank and sovereign credit risks are linked. Similar results are provided by Kallestrup et al. (2016)

who highlight that sovereign CDS premiums are significantly affected by the foreign asset holdings of their domestic banks. Other studies include, those by Eichengreen et al. (2012) who focus on individual bank level CDS data to examine the international transmission channels of the US subprime crisis. In a related study, Dooley and Hutchison (2009) explore the effect of various news announcements on CDS spreads during the crisis. Furthermore, Jorion and Zhang (2007, 2009) use stock and CDS data to investigate the effects and various channels of credit contagion. Finally, Billio et al. (2014) examine the changes in sovereign and credit risk by analyzing the link between sovereign, bank and insurance sectors.

The global financial crisis shows that a shock in a small part of the US economy was transmitted to the rest of the sectors of the economy and then spread globally. Such market comovements can have adverse effects to investors wishing to differentiate their portfolios, as well as on the decisions of domestic and international policy makers. The first goal of this study is to investigate whether contagion occurred across the European and the US financial markets after the shock of the September 15th, 2008, which is the date when Lehman Brothers filed for Chapter 11 bankruptcy, specifically between equity, sovereign bond, bank sector CDS and insurance sector CDS markets. Secondly, the analysis investigates contagion patterns, which arise not only through linear dependence (i.e. correlation), but also through asymmetric and extremal cross market dependence. Specifically, in order to draw a more complete picture of contagion, the paper explores four different channels of contagion using statistical tests based on correlation, coskewness, cokurtosis and covolatility. Before shedding light to these issues, we briefly refer to the definition of contagion used in our analysis.

In this study we adopt the same definition for contagion as in Forbes and Rigobon (2002), namely "shift-contagion". The authors distinguish between "normal" interdependence, which is a high level of interconnectedness across markets during all states of the world, and contagion which is a significant increase in cross-market linkages after a shock has occurred to one or more markets. The normal level of interdependence might be due to preexisting market linkages, such as trade channels, financial flows, and exposure to common shocks. The presence of "shift-contagion" implies that a shock, defined as a high volatility event, has caused the normal interconnectedness between markets to become unstable. The main advantage of this definition is that it provides a clear empirical framework, which allows us to test whether the linkages between two markets increased in the crisis period compared to the tranquil period prior to the crisis. Furthermore, it provides a broad view of contagion, which enables us to explore different channels of contagion, both linear and nonlinear. [1]

A decrease in asset returns and an increase in volatility is a common characteristic of a financial crisis. This is consistent with a risk-averse investor realizing higher returns in the pre-crisis period, in exchange for undertaking greater risk in the crisis period (see Sharpe, 1964; Lintner, 1965; Black, 1972). The earliest tests for contagion (King and Wadhwani (1990)), focused on whether the cross-correlation between the asset returns of two markets changed during the crisis period compared to the pre-crisis period. The base approach we use to examine for evidence of contagion across financial markets follows the correlation

[1] An extensive review of the literature of financial contagion, including the various definitions and different empirical approaches used to measure contagion is provided by Dornbusch et al. (2000), Pericoli and Sbracia (2003), Dungey et al. (2005) and Forbes (2012).

analysis framework developed by Forbes and Rigobon (2002), who correct for the bias due to the presence of heteroskedasticity in market returns that is inherent in earlier correlation tests.

However, there is considerable evidence that the distribution of asset returns cannot be adequately described by the first two moments (see among others Kraus and Litzenberger, 1976 and Harvey and Siddique, 2000). Several authors (Harvey and Siddique, 2000; Smith, 2007; Poti and Wang, 2010) show that coskewness and cokurtosis can be highly important dimensions of risk. Kostakis et al. (2012) document that stock returns with negative coskewness and positive cokurtosis values, i.e., with respect to the market portfolio returns, yield significant premiums over counterpart firms with positive coskewness and negative cokurtosis, respectively. An important characteristic of asset returns is that the return distribution after a shock switches from negative skewness to positive skewness, which can be attributed to investors preferring assets whose returns are right-skewed to asset returns that are left-skewed (Fry et al., 2010). An additional feature of asset returns is that they exhibit leptokurtic behavior, with kurtosis rising during the crisis period. Brunnermeier and Pedersen (2009) show that the lower kurtosis observed during the tranquil period is due to investors preferring securities with positive return and negative skewness. However, they find that after a crisis, investors end up holding securities with negative returns and negative skewness, leading to higher kurtosis. Fry et al. (2018) establish a theoretical motivation for testing for higher order moments by connecting the higher order comoments with the risk properties of agents’ utility functions. Hasler and Ornthanalai (2018) suggest that financial contagion arises because investors pay fluctuating attention to news.

Specifically, they show theoretically and empirically that as a negative shock hits one market, investors pay more attention to it.

The first of the methodologies we use to search for transmission channels operating through higher order comoments, was developed by Fry et al. (2010), who propose a new class of tests for financial contagion based on changes in asymmetric dependence, which is measured by coskewness (the relationship between the returns and volatility). They show that the coskewness based tests identify additional transmission channels, which are not detected by tests based on correlation. More recently, Fry-McKibbin and Hsiao (2018), develop a new line of tests based on extremal dependence. Their tests capture changes in various aspects of the distributions of asset returns, such as cokurtosis (the relationship between the returns and skewness) and covolatility (the relationship between the volatility of two markets).

Our initial findings based on correlation tests indicate that contagion occurred both within and across European and US financial markets, with the US insurance sector CDS and European equities being the most affected. The coskewness test exposed new channels of contagion, particularly among bank and insurance CDS and also between them and the majority of the remaining indices. The results based on extremal dependence (i.e., cokurtosis and covolatility) revealed additional cross-market linkages which further underline the systemic importance of the bank and insurance sector. The cokurtosis tests showed that contagion was widespread within the US market, but also transmitted across US and European indices. Finally, the covolatility test found significant contagion effects, especially through the channels of the CDS, equity and bond markets.

The remaining of the paper proceeds as follows; Section 2 describes the tests for contagion used in this study. Section 3 describes the data and presents the empirical analysis. Finally, Section 4 concludes the paper.

2. Methodological approaches

This section provides a brief description of statistical tests used to examine linear and nonlinear channels of financial contagion. The linear (mean) channel of contagion is investigated using the correlation-based contagion tests proposed by Forbes and Ribogon (2002). Furthermore, the asymmetric dependence test developed by Fry et al (2010) are employed to study the coskewness channel of contagion. Lastly, the Fry-McKibbin and Hsiao (2018) extremal dependence tests are used to explore the cokurtosis and covolatility channels.

Prior to testing for contagion, the sample is divided into two sets, the tranquil period prior to the crisis and the period after the occurrence of the shock (i.e. the crisis period). The pre- and crisis periods are denoted as x and y. The sample sizes are T for the full sample, T_x for the pre-crisis period and T_y for the crisis period. The correlation between the asset returns for the two markets is ρ_x for the non-crisis period and ρ_y for the crisis period. Let the source asset market be denoted as i and the recipient market of contagion as j. The asset returns are r_i and r_j for markets i and j respectively. The means of asset returns for i and j during the pre- and crisis periods are $\mu_{x,i}$, $\mu_{x,j}$, $\mu_{y,i}$ and $\mu_{y,j}$, while the standard deviations of asset returns for i and j during the pre- and crisis periods are $\sigma_{x,i}$, $\sigma_{x,j}$, $\sigma_{y,i}$ and $\sigma_{y,j}$.

2.1 Contagion test based on changes in correlation

Forbes and Rigobon (2002) define contagion as an increase in the heteroskedasticity adjusted correlation coefficient, which is defined as:

$$v_y = \frac{\rho_y}{\sqrt{1+\delta(1-\rho_y^2)}}, \qquad \text{where } \delta = \frac{\sigma_{y,i}^2 - \sigma_{x,i}^2}{\sigma_{x,i}^2} \tag{1}$$

The authors estimate a vector autoregressive model (VAR) model and use the variance-covariance estimates from this model to calculate the unconditional correlation coefficient between the market where the shock originated and a recipient market. Furthermore, they make the assumptions that there are no omitted variables and endogeneityand use t-tests to examine if there is a significant increase in any of the correlation coefficients during the crisis period. The "no contagion" null, $H_0: v_y = \rho_x$, against the "contagion" alternative, $H_1: v_y > \rho_x$, is tested using the following statistic:

$$FR(i \rightarrow j) = \frac{\frac{1}{2} ln\left(\frac{1+\hat{v}_y}{1-\hat{v}_y}\right) - \frac{1}{2} ln\left(\frac{1+\hat{\rho}_x}{1-\hat{\rho}_x}\right)}{\sqrt{\frac{1}{T_y-3} + \frac{1}{T_x-3}}}. \tag{3}$$

The Forbes and Ribogon (2002), $FR(i \rightarrow j)$, statistic examines the linear (correlation) channel of contagion. Specifically, it tests for contagion from the expected returns of market i to the expected returns of market j.

2.2 Contagion tests based on changes in coskewness

Fry et al. (2010) argue that linear (correlations) channel is not enough to fully reveal all patterns of contagion, and that important information can be obtained from asymmetric dependence. The coskewness channel of contagion captures changes in coskewness which emerge from the interaction between expected returns and volatility across markets. To explore the coskewness channel of contagion Fry et al. (2010) developed the following statistic:

$$CS_{mn}\left(i \to j; r_i^m, r_j^n\right) = \left(\frac{\hat{\psi}_y\left(r_i^m, r_j^n\right) - \hat{\psi}_x\left(r_i^m, r_j^n\right)}{\sqrt{\frac{4\hat{v}_y + 2}{T_y} + \frac{4\hat{\rho}_x^2 + 2}{T_x}}} \right)^2, \tag{4}$$

where $$\hat{\psi}_k\left(r_i^m, r_j^n\right) = \frac{1}{T_k} \sum_{t=1}^{T_k} \left(\frac{r_{i,t} - \hat{\mu}_{k,i}}{\hat{\sigma}_{k,i}} \right)^m \left(\frac{r_{j,t} - \hat{\mu}_{k,j}}{\hat{\sigma}_{k,j}} \right)^n, \quad k = x, y, \tag{5}$$

$m, n = 1, 2$ and $\hat{v}_y$ the estimator of v_y defined in (1).

The CS_{12} (CS_{21}) coskewness contagion test examines whether a change to the expected returns (volatility) of the source market led to a change to the volatility (expected returns) of the recipient market. To test whether there is a significant change in coskewness, they formulate the following hypotheses:

$$H_0\colon \psi_y\left(r_i^m, r_j^n\right) = \psi_x\left(r_i^m, r_j^n\right), \qquad H_1\colon \psi_y\left(r_i^m, r_j^n\right) \neq \psi_x\left(r_i^m, r_j^n\right), \tag{7}$$

where $m, n = 1, 2$. Under the null hypothesis of "no contagion", coskewness contagion tests are asymptotically distributed as: $CS_{12}(i \to j), CS_{21}(i \to j) \overset{d}{\to} X_1^2$.

2.3 Contagion tests based on changes in cokurtosis

The coskewness test is not always enough to capture the full scope of contagion. Additional transmission channels may arise through extremal dependence. The cokurtosis channel of contagion captures the interaction between expected returns and skewness across markets. To detect contagion from the source market i to the recipient market j through the cokurtosis channel Fry-McKibbin and Hsiao (2018) suggest the following statistic:

$$CK_{mn}\left(i \to j; r_i^m, r_j^n\right) = \left(\frac{\hat{\xi}_y\left(r_i^m, r_j^n\right) - \hat{\xi}_x\left(r_i^m, r_j^n\right)}{\sqrt{\frac{18\hat{v}_y^2 + 6}{T_y} + \frac{18\hat{\rho}_y^2 + 6}{T_x}}} \right)^2, \quad \text{where} \tag{8}$$

$$\hat{\xi}_y\left(r_i^m, r_j^n\right) = \hat{\psi}_y\left(r_i^m, r_j^n\right) - \left(3\hat{v}_y\right), \quad \hat{\xi}_x\left(r_i^m, r_j^n\right) = \hat{\psi}_x\left(r_i^m, r_j^n\right) - \left(3\hat{\rho}_x\right), \tag{9}$$

$m, n = 1, 3$ and $\hat{v}_y$ the estimator of v_y defined in (1).

The first (second) statistic, CK_{13} (CK_{31}), detects contagion from the expected returns (skewness) of the source market i to the skewness (expected returns) of the recipient market j. To test whether there is a significant change in cokurtosis, the following hypotheses are made:

$$H_0: \xi_y\left(r_i^m, r_j^n\right) = \xi_x\left(r_i^m, r_j^n\right), \quad H_1: \xi_y\left(r_i^m, r_j^n\right) \neq \xi_x\left(r_i^m, r_j^n\right). \tag{10}$$

Under the null hypothesis of "no contagion", tests of contagion based on changes in cokurtosis are asymptotically distributed as: $CK_{13}(i \to j), CK_{31}(i \to j) \xrightarrow{d} X_1^2$.

2.4 Contagion test based on changes in covolatility

Changes in the relation between the returns volatility of one market with the returns volatility of another market from negative to positive after the shock has occurred, reveals the volatility smile effect through the covolatility channel in the crisis period. The covolatility statistic, proposed by Fry-McKibbin and Hsiao (2018), for testing for contagion from market i to market j is given by the following equation:

$$CV_{22}\left(i \to j; r_i^2, r_j^2\right) = \left(\frac{\hat{\xi}_y\left(r_i^2, r_j^2\right) - \hat{\xi}_x\left(r_i^2, r_j^2\right)}{\sqrt{\frac{4\hat{v}_y^4 + 16\hat{v}_y^2 + 4}{T_y} + \frac{4\hat{\rho}_x^4 + 16\hat{\rho}_x^2 + 4}{T_x}}} \right)^2, \quad \text{where} \qquad (11)$$

$$\hat{\xi}_y\left(r_i^2, r_j^2\right) = \hat{\psi}_y\left(r_i^2, r_j^2\right) - \left(1 + 2\hat{v}_y^2\right), \quad \hat{\xi}_x\left(r_i^2, r_j^2\right) = \hat{\psi}_x\left(r_i^2, r_j^2\right) - (3\hat{\rho}_x). \qquad (12)$$

To test whether there is a significant change in covolatility, the following hypotheses are made:

$$H_0 : \xi_y\left(r_i^2, r_j^2\right) = \xi_x\left(r_i^2, r_j^2\right), \quad H_1 : \xi_y\left(r_i^2, r_j^2\right) \neq \xi_x\left(r_i^2, r_j^2\right). \qquad (13)$$

Under the null hypothesis of "no contagion", tests of contagion based on changes in covolatility are asymptotically distributed as: $CV_{22}(i \to j) \xrightarrow{d} X_1^2$.

3. Data and empirical analysis

The dataset is composed of daily observations of the equity, volatility, government bond, insurance sector CDS and bank sector CDS indices for Europe and the US. The analysis focuses on assets in relevance to the banking sector, thus exemplified the role of this sector in stressful times. In particular, many studies exemplify the fact that crisis events usually trigger systemic events through the banking sector, while several authors have identified strong evidence that bank values co-vary both in tranquil, but mainly in stressful periods, either as a result of common shocks, or as a consequence of trouble at one bank (Iyer and Peydro, 2011). Moreover, explanations of systemic risk fall into three broad and overlapping categories. The first defines systemic risk as exposure to a common shock. If all banks have an exposure to commercial real estate loans, then a shock to the real estate sector causes losses to every bank in the system with serious detrimental effects to the real economy. This type of exposure could arise as a natural consequence of bank diversification (Wagner, 2010), or it could also reflect a strategic decision to take advantage of limited liability so as to externalise some of the costs of failure (Acharya, 2009), or to capitalise upon the regulator's unwillingness to allow many banks to fail together (Acharya and Yorulmazer, 2007; Farhi and Tirole, 2012). The second approach to systemic risk is concerned with structural funding risks in the banking sector. Precisely, because banks fund long-lived and hard-to-sell assets with short-dated deposits and wholesale loans, they are exposed to runs, either by depositors or short-term bank lenders. It is well-understood that an unexpectedly large withdrawal of funds can cause bank insolvency (Diamond and Dybvig, 1983). When such phenomena happen, a problem that could have been contained within a few banks is transmitted to the entire banking sector, and causes widespread bank failure (Allen and Gale, 2000; Freixas, Parigi, and Rochet, 2000). Finally, a final strand of the literature on contagion concentrates upon the topology of the networks through which shocks are transmitted. Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) show that densely-connected networks are better able to absorb small shocks, but that they amplify the effects of larger shocks, such as crisis events. May, Levin, and Sugihara (2008) and Haldane and May (2011) explain the propagation of shocks through banking.

All indices are retrieved from Datastream and reported in Table A1 in the Appendix. Specifically, the two equity indices are the Euro Stoxx 50 index (EUEQ) and the S&P 500 index (USEQ), for Europe and the US respectively. The VSTOXX (EUVOL) is a volatility index based on option prices on the Euro Stoxx 50 index, while the CBOE volatility index or VIX (USVOL) is based on options written on the S&P 500 index. The bond indices for the European Monetary Union (EMU) and the US (EMUGB and USGB respectively) are based on five-year sovereign bonds. Finally, the credit default swaps indices are based on Thomson Reuter's five-year CDS data for the European and US bank (EUBCDS and USBCDS) and insurance sectors (EUICDS and USICDS). We compute the continuously compounded daily returns for all indices, $r_{i,t}$, using the formula: $r_{i,t} = \ln(p_{i,t}/p_{i,t-1})$, where p_{it} denotes the daily closing price of index i on day t. The mean, standard deviation, skewness, kurtosis and correlation coefficients of $r_{i,t}$ for the pre- and crisis periods are reported in Table A2 of the Appendix.

The sample period is set from January 15, 2004 to January 14, 2012, for a total of 2088 observations. The crisis event is set to September 15, 2008, which is the date when Lehman Brothers filed for Chapter 11 bankruptcy. Therefore, the sample is divided into two periods at the date when the shock occurred; the pre-crisis period from January 15, 2004 to September 15, 2008 and the crisis period from September 16, 2008 to January 14, 2012, for a total of 1044 observations for each sub-period. Overall, we observe from Table A2 that all indices became more volatile, since the standard deviation increased during the period after the shock, compared to the tranquil period.

We apply the econometric methodology described in Section 2, to investigate linear and nonlinear channels of contagion between European and US markets during the global financial crisis. There are three cases of contagion examined: i) contagion across European financial markets, ii) contagion across US financial markets, and iii) contagion between European and US financial markets.

To compute the Forbes and Rigobon test statistics as well as the adjusted unconditional correlation coefficient needed for the coskewness, cokurtosis and covolatility tests, the daily market returns are filtered with a 29-lag VAR model[2]. The residuals estimated from the VAR model are used in computing the tests of contagion.

The results of the tests of contagion are presented in Tables 1 to 4. In each of the tables, the first column indicates the source market, while the first line features the recipient market. Furthermore, in each table, the upper left quarter and the lower right quarter report the test results for contagion within Europe and the US, respectively. The other two quarters refer to the contagion test results across Europe and the US. The figures are test statistics values, while those in parenthesis are p-values. The null hypothesis is "no contagion" and the rejection of the null hypothesis implies that contagion has occurred.

4.1 Results of the Forbes and Rigobon (2002) correlation test

Table 1 presents the empirical results of the Forbes and Rigobon (2002) test, which examines contagion from the expected returns of one market to the expected returns of a second market, based on a significant change in cross-correlation. The empirical findings illustrate that only 26 out of the 90 entries indicate contagion at the 5% significance level.

[Insert Table 1 about here]

Within Europe, results suggest the presence of contagion between the equity index and the bank and insurance CDS indices. Furthermore, significant contagion effects occurred from the insurance sector CDS to the bank sector CDS index and from the government

[2] The Lagrange Multiplier autocorrelation test indicates no autocorrelations in the residuals at the 1% significance level.

bond to the equity index. Within the US, it is evident that shocks propagate between the insurance sector CDS index and all other indices, with the exception of the equity index, which is affected only by the bank CDS index. As for contagion across regions, we observe that contagion runs from the US insurance CDS market to all the European indices, with the exception of the equity index. By contrast, the US insurance CDS index is affected by both European CDS indices and the volatility index. In addition, contagion is transmitted to the European equity index running from the US bank CDS, sovereign bond and volatility indices. Finally, contagion spreads from the European bank CDS index to the US equity index and between the sovereign bond indices in both regions.

4.2 Results of the Fry et al. (2010) coskewness test

Tables 2a and 2b present the results for the coskewness tests of contagion. Results reveal additional evidence of contagion through the coskewness channel, with 56 entries in each table having a p-value less than the 5% significance level. The findings of the coskewness tests indicate the systemic importance of the banking and insurance sectors (see Gropp and Moerman, 2004 and Allen and Carletti, 2006, respectively), with contagion affects being prominent among bank and insurance CDS and also between the CDS and the majority of the remaining indices, for both regions.

[Insert Tables 2a and 2b about here]

The $CS12$ test results highlight the contagion linkages from the expected of one market (source) to the volatility of a second market (recipient). It is evident that among the European markets such contagion links originate from the sovereign bond and volatility indices towards the equity index, while the volatility index is also affected by the equity index. The sovereign bond index remains unaffected by the rest of the European indices. For the US markets, apart from the bank and insurance CDS channels, contagion is found to transmit from the equity index to the sovereign bond index. The $CS12$ test reveals further contagion channels across the two regions, with the EMU sovereign bond and equity markets affecting the US sovereign bond market, while the US volatility index is affected by the European bond and volatility indices. Significant effects of contagion are revealed from the US equity and sovereign bond sectors towards their European counterparts and from the US volatility index to the European equity index. The European volatility index is unaffected by any of the US indices.

The results of the $CS21$ test, which detects contagion from the volatility of one market to the expected returns of a second market, are reported in Table 2b. Again, we find significant evidence of contagion through the coskewness channel, originating from the European and US banking and insurance sectors to the majority of the remaining indices. Specifically, for the European region the $CS21$ test detects significant contagion patterns, from the equity market to all other markets and from the volatility index to the bank sector CDS and equity indices. The EMU sovereign bond index does not seem to affect any of the other indices. In the case of the US, additional linkages include those from the sovereign bond index to all indices except the volatility index, and from the equity index to the bank sector CDS index. Regarding additional contagion links across the two regions, the contagion effects that are most prominent, originate from both sovereign bond indices and the European equity index.

4.3 Results of the Fry-McKibbin and Hsiao (2018) cokurtosis test

The results for the extremal dependence tests based on cokurtosis and presented in Tables 3a and 3b, provide strong evidence of contagion through the fourth-order comoments. The cokurtosis tests reveal an even greater number of cross-market contagion linkages during the global financial crisis compared to those detected from the coskewness tests. Specifically, the $CK13$ test (Table 3a) and $CK31$ test (Table 3b) detect 77 and 75 contagion links, respectively.

[Insert Tables 3a and 3b about here]

According to the $CK13$ test which captures contagion from the expected returns of the source market to the skewness of the recipient market, the European bank sector CDS, the insurance sector CDS and volatility indices are affected by all European indices. The equity index is not affected only by the volatility index. On the other hand, contagion is transmitted to the sovereign bond index only from the equity index. In the US region, contagion is present across all markets during the global financial crisis. Shocks originating from European markets returns spread towards all US markets skewness, with the exception of the US equity index which is unaffected by both European CDS indices and the US volatility index, which is unaffected by the European equity index. Contagion spread towards the European bank and insurance CDS indices from all US indices, while the EMU sovereign bond index is affected by its US counterpart and the US bank CDS index. Moreover, contagion transmits from all US markets, except from the sovereign bond index, to the European equity index. Finally, contagion spreads to the European volatility index from the US insurance CDS, equity and volatility indices.

Similar results are obtained from the $CK31$ test, which detects contagion from the skewness of the source market to the expected return of the recipient market. In particular, in Europe, changes in cokurtosis are prominent from the bank CDS, insurance CDS, equity indices and to a lesser extent from the volatility index, with the bond index affecting only the equity index. Contagion is widespread across all financial markets in the US, with the exception of the US insurance CDS and equity indices that do not affect the equity and volatility indices respectively. Contagion effects spread from the European and US bank and insurance CDS indices towards the financial markets of both regions. Furthermore, contagion transmits from the European equity markets to all US markets and from the US government bond and volatility indices to all European indices. The effects of contagion are less prominent when the EMU sovereign bond and European volatility and the US equity channels are considered as origins.

4.4 Results of the Fry-McKibbin and Hsiao (2018) covolatility test

The results for the covolatility test, which examines significant changes in volatility spillovers after a shock, are reported in Table 4. Overall, the results suggest contagion patterns similar to those obtained for the cokurtosis channel. Specifically, 76 entries in Table 4 support the contagion hypothesis through the covolatility channel. This result suggests that the effects of the global financial crisis were widespread across all markets for both regions, especially through the banking and insurance sector CDS channels as indicated by the magnitude of the $CV22$ statistic.

[Insert Table 4 about here]

In Europe, contagion transmits among all indices, with no evidence of contagion to the equity index from the volatility index. Furthermore, the covolatility test does not detect any contagion between the volatility of the two CDS indices and the volatility of the sovereign bond index. In the US, contagion is spread across all financial markets, with the value of the covolatility statistics related to the bank and insurance sectors being significantly higher. Based on the covolatility test, contagion across both regions is similarly extensive. The channels of contagion that are more prominent include the European insurance sector CDS, sovereign bond and volatility indices and the US bank sector CDS, sovereign bond and volatility indices.

The obtained results for the case of the US are consistent with the increasing uncertainty fueled by events, such as the collapse of the subprime mortgage market. This type of uncertainty persists, in spite of certain actions taken by the Federal Reserve and other central banks to increase liquidity available to banks. The high levels of uncertainty are also fed by the increasing instability in the European banking sector, while it also spreads to the equity market. Similar results are taken for the European markets, given that the European Central Bank did not match the actions taken by the Fed to provide higher levels of liquidity, both for the European banking sector and the real economy (Bartram and Bonard, 2009). At the same time, the presence of extended contagion clearly supports that the benefits of risk diversification diminished during crisis periods. In addition, the presence of contagion across markets is a proof of strong evidence for the 'wake-up call' hypothesis, which opens up the intriguing possibility that government policies can mitigate contagion (Goldstein et al., 2000), since domestic fundamentals are likely to play a dominant role in the transmission of the crisis. If macro-fundamentals matter during a crisis, cross-country differences in government policies (i.e., as in the case between US and Eurozone) could potentially explain the relative exposure to the crisis. Strong contagion can also be explained in the case where European firms are in sectors that are highly integrated with US markets, such as technology. The findings are also very indicative for the validity of the ‘banking channel’ hypothesis for global contagion during the crisis. A number of authors have stressed the importance of this channel, even for equity market contagion (Van Rijckeghem and Weder, 2001; Tong and Wei, 2009; among others).

A central element of the crisis was a freezing of credit and inter-bank markets and a liquidity squeeze that made it difficult for financial and non-financial institutions to obtain capital. This finding is closely related to the literature that stresses the role of (il)liquidity in causing or exacerbating crise events (Adrian and Shin, 2010; Brunnermeier and Pedersen, 2009). The effect of such banking problems also clearly indicates firms with financing constraints, as well as firms with more interest rate exposures, as they may have shorter maturity debt and thus face steeper refinancing costs (Almeida et al., 2012). Finally, the results are in relevance to the concepts of risk aversion and liquidity. In particular, the risk aversion of investors (proxied by the VIX index in our case) may substantially increase during the crisis, making them shun risky assets and flee into safer assets, particularly, government bonds (Baker et al., 2009; Bekaert et al., 2011).

4. Concluding remarks

This study used the Forbes and Rigobon (2002) correlation test, the Fry et al. (2010) coskewness test, and the Fry-McKibbin and Hsiao (2018) cokurtosis and covolatility tests to examine contagion across European and US financial markets. The 2008 crisis was selected to be the decisive crisis event, while data on bank sector's CDS, insurance sector's CDS, sovereign bond, equity and volatility indices spanning the period 2004 to 2012 were used. Our initial results based on the correlation test show that contagion occurred across financial markets during the global financial crisis, especially through the channels of the insurance and equity sectors. However, higher order moment contagion tests revealed linkages across markets that were not previously detected when using correlation based tests. The additional channels of contagion most prominently supported by the asymmetric and extremal dependence tests were that of the bank and insurance CDS sectors.

The empirical findings allow identifying contagion across financial markets and regions and could be helpful for the design of specific stabilization policies. The tests generated results as an additional tool for regulators and policy makers to assess the effectiveness of their policies and the communication of their actions. In particular, our findings carry important implications for investors, policy makers and international organizations, such as International Monetary Fund (IMF), with regard to the linkages among the markets and their real economy sectors. For instance, investors may benefit from the different vulnerability of the markets and real economy sectors, since holding a portfolio with equities from diverse sectors is less subject to systematic risks. From policymakers and international organizations' perspective, the results provided useful information about the directions for possible future policy decisions to protect countries and investors from future financial crises.

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Table 1: The Forbes and Rigobon (2002) $FR(i \rightarrow j)$ correlation-based contagion test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		0.08	3.95	**-7.46**	6.86	3.99	**-5.16**	0.61	**-3.67**	5.10
		(0.53)	(1.00)	**(0.00)**	(1.00)	(1.00)	**(0.00)**	(0.73)	**(0.00)**	(1.00)
EUICDS	**-2.22**		2.73	**-4.20**	3.48	2.36	**-4.21**	0.60	-1.26	2.23
	(0.01)		(1.00)	**(0.00)**	(1.00)	(0.99)	**(0.00)**	(0.73)	(0.10)	(0.99)
EMUGB	2.53	2.69		**-3.26**	2.60	3.18	-1.26	**-3.93**	-1.08	2.75
	(0.99)	(1.00)		**(0.00)**	(1.00)	(1.00)	(0.10)	**(0.00)**	(0.14)	(1.00)

EUEQ	**-2.77**	**-1.76**	-0.21		7.37	-1.47	4.12	1.26	-1.51	1.96
	(0.00)	**(0.04)**	(0.42)		(1.00)	(0.07)	(1.00)	(0.90)	(0.07)	(0.98)
EUVOL	4.99	3.24	2.37	3.26		3.07	**-2.30**	0.50	1.04	1.56
	(1.00)	(1.00)	(0.99)	(1.00)		(1.00)	**(0.01)**	(0.69)	(0.85)	(0.94)
USBCDS	3.97	3.49	4.47	**-5.75**	4.73		**-3.01**	4.09	**-4.96**	4.41
	(1.00)	(1.00)	(1.00)	**(0.00)**	(1.00)		**(0.00)**	(1.00)	**(0.00)**	(1.00)
USICDS	**-6.59**	**-5.70**	**-2.36**	4.67	**-3.42**	**-5.52**		**-4.36**	4.69	**-4.33**
	(0.00)	**(0.00)**	**(0.01)**	(1.00)	**(0.00)**	**(0.00)**		**(0.00)**	(1.00)	**(0.00)**
USGB	0.12	0.91	**-3.09**	**-1.69**	1.22	3.36	**-3.60**		-0.38	1.66
	(0.55)	(0.82)	**(0.00)**	**(0.05)**	(0.89)	(1.00)	**(0.00)**		(0.35)	(0.95)
USEQ	-0.72	0.21	0.74	-0.94	3.32	-0.86	3.87	2.31		7.55
	(0.24)	(0.58)	(0.77)	(0.17)	(1.00)	(0.19)	(1.00)	(0.99)		(1.00)
USVOL	4.33	2.69	3.37	**-2.47**	3.01	3.47	**-2.27**	1.67	2.38	
	(1.00)	(1.00)	(1.00)	**(0.01)**	(1.00)	(1.00)	**(0.01)**	(0.95)	(0.99)	

Notes: The $FR(i \rightarrow j)$ test measures contagion from the expected returns of market i to the expected returns of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

Table 2.a: The Fry et al. (2010) $CS12$ coskewness-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**1304.96**	1.71	**35.86**	**5.79**	**41.24**	**188.61**	**8.93**	**5.23**	0.81
		(0.00)	(0.19)	**(0.00)**	**(0.02)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.02)**	(0.37)
EUICDS	**413.70**		3.52	**16.43**	1.16	**163.87**	**4.77**	**8.39**	**6.93**	3.43
	(0.00)		(0.06)	**(0.00)**	(0.28)	**(0.00)**	**(0.03)**	**(0.00)**	**(0.01)**	(0.06)
EMUGB	**18.84**	**84.76**		**4.82**	0.21	**79.11**	0.90	**24.94**	0.47	**6.33**
	(0.00)	**(0.00)**		**(0.03)**	(0.64)	**(0.00)**	(0.34)	**(0.00)**	(0.49)	**(0.01)**
EUEQ	**47.46**	**60.92**	3.42		**15.18**	**49.33**	**5.38**	**21.88**	0.27	0.80
	(0.00)	**(0.00)**	(0.06)		**(0.00)**	**(0.00)**	**(0.02)**	**(0.00)**	(0.61)	(0.37)
EUVOL	**54.17**	**103.41**	0.02	**25.53**		**48.29**	**65.39**	2.78	0.05	**7.29**
	(0.00)	**(0.00)**	(0.89)	**(0.00)**		**(0.00)**	**(0.00)**	(0.10)	(0.82)	**(0.01)**
USBCDS	**34.36**	**17.95**	**5.85**	2.18	0.04		**16.50**	**27.99**	**9.88**	2.34
	(0.00)	**(0.00)**	**(0.02)**	(0.14)	(0.83)		**(0.00)**	**(0.00)**	**(0.00)**	(0.13)
USICDS	**32.85**	**52.58**	1.79	0.55	1.71	**146.36**		**25.96**	0.06	0.55
	(0.00)	**(0.00)**	(0.18)	(0.46)	(0.19)	**(0.00)**		**(0.00)**	(0.81)	(0.46)
USGB	**8.84**	1.55	**16.42**	**10.78**	0.81	**174.14**	**58.56**		1.06	0.44
	(0.00)	(0.21)	**(0.00)**	**(0.00)**	(0.37)	**(0.00)**	**(0.00)**		(0.30)	(0.51)
USEQ	**22.84**	**46.98**	**5.53**	**5.98**	1.26	**44.22**	0.45	**29.47**		0.11
	(0.00)	**(0.00)**	**(0.02)**	**(0.01)**	(0.26)	**(0.00)**	(0.50)	**(0.00)**		(0.75)
USVOL	**31.25**	**56.83**	0.00	**4.20**	2.15	**8.97**	3.69	2.14	1.30	
	(0.00)	**(0.00)**	(0.99)	**(0.04)**	(0.14)	**(0.00)**	(0.05)	(0.14)	(0.25)	

Notes: The $CS12$ statistic measures contagion from the expected returns of market i to the volatility of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

Table 2.b: The Fry et al. (2010) $CS21$ coskewness-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**396.55**	**18.24**	**42.32**	**51.70**	**34.35**	**32.54**	**8.76**	**21.45**	**30.69**
		(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
EUICDS	**1361.37**		**84.69**	**57.60**	**102.83**	**18.39**	**51.91**	1.56	**45.72**	**57.37**
	(0.00)		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	(0.21)	**(0.00)**	**(0.00)**
EMUGB	1.76	3.52		3.18	0.02	**6.03**	1.78	**16.70**	**5.32**	0.00
	(0.18)	(0.06)		(0.07)	(0.89)	**(0.01)**	(0.18)	**(0.00)**	**(0.02)**	(0.99)
EUEQ	**40.22**	**17.38**	**5.17**		**27.22**	2.41	0.54	**11.48**	**6.05**	**4.61**
	(0.00)	**(0.00)**	**(0.02)**		**(0.00)**	(0.12)	(0.46)	**(0.00)**	**(0.01)**	**(0.03)**
EUVOL	**6.07**	1.16	0.22	**14.25**		0.05	1.69	0.82	1.20	2.21
	(0.01)	(0.28)	(0.64)	**(0.00)**		(0.83)	(0.19)	(0.36)	(0.27)	(0.14)
USBCDS	**41.25**	**159.96**	**76.84**	**44.57**	**46.44**		**142.25**	**171.26**	**40.16**	**8.77**
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
USICDS	**190.42**	**4.84**	0.91	**5.40**	**65.93**	**16.97**		**58.75**	0.45	3.77
	(0.00)	**(0.03)**	(0.34)	**(0.02)**	**(0.00)**	**(0.00)**		**(0.00)**	(0.50)	(0.05)
USGB	**9.01**	**8.35**	**24.52**	**20.53**	2.73	**28.46**	**25.87**		**27.85**	2.14
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	(0.10)	**(0.00)**	**(0.00)**		**(0.00)**	(0.14)
USEQ	**5.57**	**7.12**	0.48	0.26	0.05	**10.88**	0.06	1.12		1.40
	(0.02)	**(0.01)**	(0.49)	(0.61)	(0.82)	**(0.00)**	(0.81)	(0.29)		(0.24)
USVOL	0.83	3.40	**6.24**	0.72	**7.09**	2.39	0.54	0.44	0.10	
	(0.36)	(0.07)	**(0.01)**	(0.39)	**(0.01)**	(0.12)	(0.46)	(0.51)	(0.75)	

Notes: The $CS21$ statistic measures contagion from the volatility of market i to the expected returns of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

Table 3.a: The Fry-McKibbin and Hsiao (2018) $CK13$ cokurtosis-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**10205.55**	3.33	**225.57**	**87.79**	**3993.37**	**46997.36**	**229.70**	2.48	**266.04**
		(0.00)	(0.07)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	(0.11)	**(0.00)**
EUICDS	**10.90**		0.05	**302.17**	**88.73**	**5253.58**	**1266.01**	**170.67**	0.20	**151.76**
	(0.00)		(0.83)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	(0.65)	**(0.00)**
EMUGB	**164.54**	**3211.12**		**13.68**	**10.32**	**3481.81**	**55.63**	**48.76**	**8.15**	**38.43**
	(0.00)	**(0.00)**		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
EUEQ	**1350.96**	**5.49**	**20.81**		**7.65**	**1252.60**	**6320.21**	**29.55**	**18.24**	1.80
	(0.00)	**(0.02)**	**(0.00)**		**(0.01)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	(0.18)
EUVOL	**636.94**	**934.60**	0.05	0.62		**1058.75**	**16549.73**	**95.17**	**7.99**	**160.18**
	(0.00)	**(0.00)**	(0.83)	(0.43)		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
USBCDS	**720.40**	**555.37**	**128.26**	**55.08**	3.02		**1042.38**	**775.14**	**50.92**	**10.15**
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	(0.08)		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
USICDS	**258.18**	**809.10**	0.79	**23.58**	**5.61**	**3126.96**		**131.41**	**61.31**	**82.75**
	(0.00)	**(0.00)**	(0.37)	**(0.00)**	**(0.02)**	**(0.00)**		**(0.00)**	**(0.00)**	**(0.00)**
USGB	**39.50**	**1944.80**	**11.63**	0.15	2.28	**5557.75**	**24231.76**		**51.34**	**44.93**
	(0.00)	**(0.00)**	**(0.00)**	(0.70)	(0.13)	**(0.00)**	**(0.00)**		**(0.00)**	**(0.00)**
USEQ	**93.85**	**2793.20**	0.06	**55.22**	**8.13**	**1622.13**	**6.82**	**174.29**		**109.27**
	(0.00)	**(0.00)**	(0.80)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.01)**	**(0.00)**		**(0.00)**
USVOL	**523.22**	**4687.21**	1.52	**53.89**	**3.94**	**555.55**	**216.70**	**129.23**	**4.50**	
	(0.00)	**(0.00)**	(0.22)	**(0.00)**	**(0.05)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.03)**	

Notes: The $CK13$ statistic measures contagion from the expected returns of market i to the skewness of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

Table 3.b: The Fry-McKibbin and Hsiao (2018) $CK31$ cokurtosis-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**4.21**	**125.92**	**914.18**	**520.57**	**719.11**	**308.62**	**45.92**	**40.40**	**477.32**
		(0.04)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
EUICDS	**11006.74**		**3202.82**	**20.46**	**913.11**	**632.08**	**890.84**	**1927.65**	**2849.39**	**4685.86**
	(0.00)		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
EMUGB	0.27	0.07		**4.09**	0.00	**165.01**	**4.83**	**8.27**	2.26	0.43
	(0.60)	(0.80)		**(0.04)**	(0.98)	**(0.00)**	**(0.03)**	**(0.00)**	(0.13)	(0.51)
EUEQ	**411.81**	**417.99**	**39.94**		**6.70**	**139.91**	**17.65**	**5.62**	**60.84**	**116.37**
	(0.00)	**(0.00)**	**(0.00)**		**(0.01)**	**(0.00)**	**(0.00)**	**(0.02)**	**(0.00)**	**(0.00)**
EUVOL	**128.75**	**93.91**	**11.70**	0.92		**11.16**	1.07	0.66	1.10	**7.56**
	(0.00)	**(0.00)**	**(0.00)**	(0.34)		**(0.00)**	(0.30)	(0.42)	(0.29)	**(0.01)**
USBCDS	**3997.72**	**4912.87**	**3196.39**	**863.71**	**908.55**		**2709.77**	**5323.97**	**1184.48**	**503.81**
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
USICDS	**46946.15**	**1171.86**	**38.22**	**6252.11**	**16410.84**	**910.03**		**24068.79**	2.85	**299.40**
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**	(0.09)	**(0.00)**
USGB	**216.52**	**178.70**	**55.84**	**61.78**	**107.24**	**834.52**	**152.03**		**226.41**	**129.13**
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**	**(0.00)**
USEQ	1.94	1.27	1.30	**15.41**	1.32	**124.17**	**76.08**	**25.09**		0.03
	(0.16)	(0.26)	(0.25)	**(0.00)**	(0.25)	**(0.00)**	**(0.00)**	**(0.00)**		(0.87)
USVOL	**298.10**	**138.26**	**30.82**	**16.61**	**173.17**	**6.05**	**126.62**	**45.00**	**142.88**	
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.01)**	**(0.00)**	**(0.00)**	**(0.00)**	

Notes: The $CK31$ statistic measures contagion from the skewness of market i to the expected returns of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

Table 4: The Fry-McKibbin and Hsiao (2018) $CV22$ covolatility-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**229.00**	0.13	**523.45**	**319.00**	**1857.76**	0.01	**276.95**	0.00	**240.38**
		(0.00)	(0.71)	**(0.00)**	**(0.00)**	**(0.00)**	(0.90)	**(0.00)**	(0.95)	**(0.00)**
EUICDS	**279.26**		0.11	**127.33**	**74.47**	**2633.59**	**574.22**	**376.03**	**65.34**	1.22
	(0.00)		(0.74)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	(0.27)
EMUGB	1.32	0.13		**5.34**	**5.50**	**743.77**	**318.41**	**32.33**	**15.76**	**6.54**
	(0.25)	(0.72)		**(0.02)**	**(0.02)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.01)**
EUEQ	**794.08**	**174.53**	**17.30**		**6.45**	**150.02**	**216.53**	**14.17**	**26.20**	**47.60**
	(0.00)	**(0.00)**	**(0.00)**		**(0.01)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
EUVOL	**389.99**	**77.52**	**6.16**	0.68		**213.37**	1.27	**35.46**	**7.94**	**13.08**
	(0.00)	**(0.00)**	**(0.01)**	(0.41)		**(0.00)**	(0.26)	**(0.00)**	**(0.00)**	**(0.00)**
USBCDS	**1858.34**	**2572.81**	**740.16**	**180.83**	**224.61**		**2023.26**	**3433.33**	**649.03**	**119.23**
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
USICDS	0.01	**573.38**	**316.83**	**215.52**	0.89	**2068.64**		**126.80**	**306.08**	**143.90**
	(0.92)	**(0.00)**	**(0.00)**	**(0.00)**	(0.34)	**(0.00)**		**(0.00)**	**(0.00)**	**(0.00)**
USGB	**274.92**	**376.86**	**36.24**	**25.05**	**38.78**	**3495.05**	**127.69**		**112.18**	**37.01**
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**	**(0.00)**
USEQ	2.03	**58.60**	**10.34**	**23.10**	3.09	**643.57**	**307.73**	**95.13**		**17.57**
	(0.15)	**(0.00)**	**(0.00)**	**(0.00)**	(0.08)	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**
USVOL	**261.98**	1.72	**4.82**	**17.70**	**17.70**	**112.47**	**150.35**	**37.04**	**34.44**	
	(0.00)	(0.19)	**(0.03)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	

Notes: The $CV22$ statistic measures contagion from the volatility of market i to the volatility of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

Appendix

Table A1: Sources of the financial sector indices

	Europe		United States	
Equity Index	EUEQ	EURO STOXX 50 Index (DJES50I)	USEQ	S&P 500 Index (S&PCOMP)
Volatility Index	EUVOL	EURO STOXX 50 Volatility Index (VSTOXXI)	USVOL	CBOE Volatility Index (VIX) (CBOEVIX)
Sovereign Bond Index	EMUGB	EMU Benchmark 5 yr. DS Gov. Index (BMEM05Y)	USGB	US Benchmark 5 yr. DS Gov. Index (BMUS05Y)
Bank Sector CDS Index	EUBCDS	EU Bank Sector 5 yr. DS CDS Index (EUBANCD)	USBCDS	US Bank Sector 5 yr. DS CDS Index (USBANCD)
Insurance Sector CDS Index	EUICDS	EU Insur. Sector 5 yr. DS CDS Index (EUINSCD)	USICDS	US Insur. Sector 5 yr. DS CDS Index (USINSCD)

Notes: The code inside the bracket below the name of the index indicates the Datastream mnemonic of the index.

Table A3: Descriptive statistics

Descriptive statistics for the pre-crisis period										
	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
Mean	0.00249	0.00129	-0.00001	0.00012	0.00067	0.00249	0.00236	0.00003	0.00005	0.00081
Std. Dev.	0.03597	0.04119	0.00184	0.01029	0.05218	0.05184	0.04092	0.00270	0.00901	0.06294
Skewness	1.08343	2.15014	-0.00364	-0.44000	0.86925	-1.29980	0.37288	0.11097	-0.35873	0.70450
Kurtosis	13.52152	30.95665	4.46548	8.23201	6.10058	31.48781	10.81201	6.21038	5.92657	8.84771

Pre-crisis period correlation										
	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		0.72234	0.25889	-0.27970	0.22759	0.25855	0.47809	0.16923	-0.11494	0.07295
EUICDS	0.72234		0.21822	-0.24623	0.24796	0.23395	0.44325	0.14435	-0.12052	0.10481
EMUGB	0.25889	0.21822		-0.41113	0.33382	0.23485	0.21193	0.57167	-0.25156	0.18963
EUEQ	-0.27970	-0.24623	-0.41113		-0.81312	-0.31983	-0.29414	-0.31168	0.48355	-0.40025
EUVOL	0.22759	0.24796	0.33382	-0.81312		0.26928	0.24540	0.26541	-0.43123	0.45215
USBCDS	0.25855	0.23395	0.23485	-0.31983	0.26928		0.41385	0.20792	-0.30103	0.24239
USICDS	0.47809	0.44325	0.21193	-0.29414	0.24540	0.41385		0.21967	-0.27450	0.22736
USGB	0.16923	0.14435	0.57167	-0.31168	0.26541	0.20792	0.21967		-0.39973	0.30151
USEQ	-0.11494	-0.12052	-0.25156	0.48355	-0.43123	-0.30103	-0.27450	-0.39973		-0.80914
USVOL	0.07295	0.10481	0.18963	-0.40025	0.45215	0.24239	0.22736	0.30151	-0.80914	

Descriptive statistics for the crisis period										
	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
Mean	0.00067	0.00011	0.00017	-0.00019	-0.00042	-0.00082	-0.00067	0.00015	0.00020	-0.00075
Std. Dev.	0.04019	0.04564	0.00236	0.01867	0.06374	0.05409	0.09494	0.00323	0.01715	0.07185
Skewness	-0.15719	-5.37533	-0.03285	0.13490	0.78845	0.02789	-13.31658	-0.14018	-0.26795	0.71784
Kurtosis	22.51380	92.85061	4.46621	7.18374	5.95402	24.86864	343.39414	8.29233	10.25302	6.62651

Crisis period correlation										
	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		0.60832	0.36477	-0.44636	0.40099	0.32821	0.11397	0.22223	-0.27716	0.30077
EUICDS	0.60832		0.36786	-0.45636	0.40668	0.32986	0.16366	0.23029	-0.29239	0.29589
EMUGB	0.36477	0.36786		-0.57288	0.49242	0.36373	0.15568	0.51138	-0.37422	0.37924
EUEQ	-0.44636	-0.45636	-0.57288		-0.77119	-0.50831	-0.17755	-0.39571	0.66127	-0.56285
EUVOL	0.40099	0.40668	0.49242	-0.77119		0.43517	0.16356	0.31991	-0.46778	0.60427
USBCDS	0.32821	0.32986	0.36373	-0.50831	0.43517		0.20890	0.33023	-0.45004	0.44172
USICDS	0.11397	0.16366	0.15568	-0.17755	0.16356	0.20890		0.09676	-0.16462	0.18187
USGB	0.22223	0.23029	0.51138	-0.39571	0.31991	0.33023	0.09676		-0.40409	0.36259
USEQ	-0.27716	-0.29239	-0.37422	0.66127	-0.46778	-0.45004	-0.16462	-0.40409		-0.76845
USVOL	0.30077	0.29589	0.37924	-0.56285	0.60427	0.44172	0.18187	0.36259	-0.76845	

Notes: EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.